USE OF EXTENDED RANGE FORECASTS IN SHIP ROUTING

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IN SHIP ROUTING

by

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ABSTRACT

Surface wave action has been proven to be the biggest deterrent to a ship's progress through the water. Until the present time forecasts of surface waves have been available for only a few days. In order to determine an optimum ship route across the ocean these wave forecasts must be extended to 15-20 days. Using three computer programs from the Fleet Numerical Weather Facility and the U.S. Weather Bureau 5-day and 30-day forecasts of the mean sea level pressures as input data, surface wave forecasts may be prepared for periods up to 30 days. When compared with the actual waves over the specified period of time, the forecast wave patterns show more skill than forecast waves derived strictly from climatology.

TABLE OF CONTENTS

1. INTRODUCTION

Optimum track ship routing (OTSR) has been in existance in the U.S. Navy for almost ten years under this specific name. An optimum track is one chosen from port to port across the ocean that will allow a ship to traverse the route in the least amount of time and also encounter less unfavorable weather. James [5] has shown that a definite increase in operational efficiency is made possible by the routing of transoceanic vessels along tracks based primarily on long-range ocean wave forecasts rather than along standard seasonal tracks. Such predicted tracks are believed to be superior to the standard seasonal routes in terms of travel time, passenger comfort, damage to cargo and ship, and fuel consumption. Absolute values for the reduction of the above items are difficult to present, but certainly the great weight of evidence presented in his evaluation supports the contention that efficiency of ship operation is improved by oceanographic ship routing. The Military Sea Transportation Service tentatively estimates that each hour saved in ship operations is a savings of $200.00 to them.

Some of the international steamer tracks in use today are modifications of routes laid out by Lt. Matthew Fontaine Maury, USN, as far back as the 1850's. Maury's routes were based on ships' logs, climatology and statistics. Today, James [4] has found that the most important parameter retarding a ship's progress is surface wave action.

Wave action actually affects a ship's progress in two ways. First simply by retarding the ship's speed through the disturbed water and secondly by making the Captain order a reduction in speed due to the violent effects of roll, pitch, and other associated motion of the ship in creating eddy resistance.

Ships not utilizing OTSR, when making a transoceanic voyage in the Northern Hemisphere, usually travel a more northerly route in the summer months and then shift to a southerly route in the stormy winter months. This usually results in avoiding the largest storms but at a great cost in time and money. Reduction in weather damage is not the whole solution, however, since the ideal situation is to save time and increase the distance traveled per day. Often times, the weather situation may be such that the off-season route has the best sea conditions.

At the present time a 5-day forecast of the surface weather phenomenon is the maximum utilized in ship routing. If this could be extended say to 15-20 days, an entire voyage could be routed across the Pacific Ocean to avoid storm areas and reduce transient time. Operationally, the procedures for ship routing are slightly different in the Atlantic and Pacific operating areas. More emphasis is placed on storm track trends and climatic means in the Pacific since the 5-day forecast covers less than half the normal crossing.

It is the purpose of this paper to derive extended range forecasts of wave heights, directions and periods for 15-20 days in advance of a proposed sailing across the Pacific Ocean.

Naturally, constant surveillance would have to be maintained over the routed vessels as the 5-day forecasts are up-dated and when sea conditions warrant, the routes would be modified to indicate a superior route.

2. COLLECTION OF DATA

The U.S. Weather Bureau publishes a 5-day forecast of the mean sea level pressures around the Northern Hemisphere and this is presented on individual maps for each of the five days. These maps are distributed on Monday, Wednesday, and Friday of each week and are portrayed on a polar stereographic 1:50,000,000 scale. The forecasts are based on a mean circulation method by averaging ten twice-daily values of pressure at standard intersections of latitude and longitude on synoptic sea level weather maps. [1] The Weather Bureau also makes 30-day forecasts using methods similar to those employed in preparing the 5-day forecasts.

These maps were utilized to obtain a surface wave forecast for an extended period of time across the Pacific Ocean. The period of time selected was 26 July 1966 to 06 August 1966, a total of 12 days. The U.S. Navy Fleet Numerical Weather Facility located at Monterey, California publishes 24 and 48-hour wind-wave prognoses which were used for the first two days of the forecast, 26 and 27 July 1966. [2] For 28, 29, and 30 July 1966 the last three maps of the U.S. Weather Bureau 5-day forecast series were applied. For the 31st of July through 6 August the 30-day mean sea level prognostic chart dated 15 July 1966 was utilized on a day to day basis.

In the following explanation, focus is placed only on one map in showing how the surface wave forecast was derived. The remaining days of the forecast were treated in a similar manner.

The first step in arriving at the forecast was to use the FNWF FAREB program. This program was written by Harry N. Farnsworth on 1 May 1965 at the Fleet Numerical Weather Facility. The basic purpose

of this program is to reconstruct any scalar field in memory in a CDC 1604 computer as a 3969-point field. An attempt will not be made to explain each step of this program in detail, however, input and output values along with an example for preparation of a field will be discussed.

Input values were extracted from the source chart by employing a plastic overlay of the standard FNWF 63 x 63 grid. If a grid overlay were not available latitude-longitude input could be used. A proper interval should be selected in order to combine sufficient pattern delineation with a minimum of data inputs. The initial guess field is considered in the interval selection and since a guess field of zero was used, an interval of two grid points or every other point was chosen. Then by superimposing the grid overlay on the source chart an initial grid point was established and grid point values were read along a J-row at a specified point spacing (every other point). A new initial point may be established whenever desired to reorient the input data. The input points selected were denoted by dots and dashes on the FNWF overlay. Since the source chart was in millibars, the values were read to the nearest millibar interpolating where necessary. When all values had been read from the source chart in the desired area and tabulated they were converted to 1000-mb heights using a standard conversion of 7.5 mb per 200 feet with a reference point of 1000 mb equal to zero feet. All values had to be coded as four digit numbers for entry on the standard IBM card. The values were assumed to be positive unless preceded by a minus sign. There were some low centers present with central pressures below 1000 mb and these were coded accordingly.

In order to assemble the card deck the identification and scaling

information was prepared. On the initial card the titling information and initial guess value were placed. The standard procedure is for the titling information to consist of the date-time group, some identifying number, in this case D1000, and then any explanatory information that might be desired such as name, etc.

The program was then put into operation and the final field constructed through smoothing, relaxation, and a combination of the two. A grid print in feet of the height of the 1000-mb surface was produced and the field packed and written on magnetic tape. As mentioned previously the main objective of this program was to get the data on tape in an organized field in order to go on to the next step.

3. WIND EXTRACTION

The next step in arriving at the wave forecast was to utilize the FNWF wind extraction program. By using the 1000-mb constant pressure surface as the input this program computes the geostrophic u, v wind components, as well as the direction and speed of the wind by solution of the geostrophic wind equation. There are, however, some limitations to this program. Wind speeds that are computed by the geostrophic wind equation are generally greater than actual speeds in regions of cyclonic trajectory curvature and less than actual speeds in regions of anticyclonic curvature.

This program was run on the 3200 computer at the Fleet Numerical Weather Facility. An example of a 3200 run sheet is shown in Appendix I. Some modifications had to be made in order to read the mean D1000 field and the climatological D1000 field taken from the U.S. Weather Bureau records. These modifications were made on a 3200 octal patch and an example of this is shown in Appendix II. The output of this program was packed and written on magnetic tape for an input to the wind waves program.

4. WIND WAVES

The next step was to derive the final product. The Fleet Numerical Weather Facility Wind Waves program with slight modifications was run on the Control Data Corporation 1604 computer to accomplish this purpose. In order to eliminate some of the steps not needed in this program a flex-tape patch (Appendix III) was made and inserted into the computer at the appropriate time.

The program input consisted of three magnetic tapes. Tape number one contained the 1000-mb field obtained in the FAREB program previously mentioned. Tape number two contained the climatological sea surface temperatures for the month of July. Tape number three was comprised of the u and v components of the wind. A fourth tape, blank pool tape, was used in order to copy the output of the program. This was necessary in making a difference field with the actual analyzed waves in order to determine the merits of the 5 and 30-day forecasts for preparing long range wave prognoses.

The Waves program corrects the geostrophic wind directions for surface friction by assuming a constant cross-contour flow of 15 degrees toward lower pressure. A stability correction is then made by reducing the wind speed depending upon the general air mass type and the sign of the surface temperature advection. For example, a mass of maritime tropical air blowing toward colder sea surface temperatures would warrant a greater reduction in wind speed than a mass of maritime polar air blowing toward warmer sea surface temperatures. The duration of the wind is determined at each grid point by computing the length of time the wind has been blowing from the same direction (within $\pm$ 22 degrees). The maximum duration has been set at 18 hours according to the

French school of thought which considers all seas to be fully developed after this length of time. An effective wind speed is then obtained by an averaging technique. The significant wave height and wave period is computed using two singular relationships established at the Fleet Numerical Weather Facility:

$$H_{1/3} = K_1 V^2 D + K_2 V \tag{4.1}$$

$$T_{1/3} = V(K_3 + K_4 D) + K_5 \tag{4.2}$$

where $H_{1/3}$ and $T_{1/3}$ are the significant wave height and period, respectively; V is the effective geostrophic wind speed; D is the duration time and K_1 to K_5 are empirical constants tuned to reduce the root mean square error.

An example of a 1604 run sheet is shown in Appendix IV. The tape set-up and instructions listed were actually used to run this program.

5. VERIFICATION

It was decided at the onset that once the forecast wave pattern was derived a comparison would be made of the derived field and the actual analyzed waves for the specified period of time. To accomplish this purpose an A-B program, called SAK and written by R. McDonald at Fleet Numerical in 1962, was utilized. This program computes a difference field using any two given fields, A and B, a pillow and root mean square error for the entire grid. Pillow and RMSE are defined as follows:

$$\text{Pillow} = \frac{\sum_{n=1}^{x} (A - B)n}{x} \qquad x \equiv \text{Dependent on number of points differenced} \tag{5.1}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{n=1}^{x} \left[(A-B) - \text{Pillow}\right]_n^2}{x}} \tag{5.2}$$

A further comparison was made of the actual analyzed waves and a wave forecast based solely on climatology. Sea level pressure normals were obtained from the U.S. Weather Bureau and a D1000 field was derived. From this field a wave forecast was made following the same basic steps as explained above.

6. CONCLUSIONS AND ACKNOWLEDGEMENTS

Appendix V portrays the results of the verification that was outlined in Section 5. It is readily apparent that the waves derived from the 5 and 30-day forecasts show more skill than those waves derived solely from climatological data. The reason the values of RMSE in both cases might seem to be large is that data was extracted only in the Pacific Ocean region and the rest of the grid left blank. When the SAK program computes this error the whole grid is taken into account resulting in the large values. Based on this fact, it is felt that the procedures outlined in this paper can be used in extending wave forecasts beyond those that exist today with a good degree of certainty.

The author wishes to thank Professor George J. Haltiner, Chairman, Department of Meteorology and Oceanography, U.S. Naval Postgraduate School, Monterey, California for his guidance and a special thanks goes to Mr. Norman Stevenson, Data Dynamics, Monterey, California for his invaluable assistance in this endeavor.

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Finally, the author wishes to thank the personnel at Fleet Numerical Weather Facility, Monterey, California for the use of their computers and for providing the data.

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APPENDIX I

3200 Run Sheet

Run # 12 Date 9-26-66 Est. Time 10 Stop if exceeds ____

Programmer Truax Actual Time ____________

Rush ______ Routine ______ Rockpile ______ Listing Only ________

( ) ________ BPI ___ IN ___ OUT ___ List & Binary Deck ______

( ) ________ BPI ___ IN ___ OUT ___ List & Mini Tape ________

( ) ________ BPI ___ IN ___ OUT ___ Stack for Transmit ______

( ) ________ BPI ___ IN ___ OUT ___ Program Requires: Drum ___ Printer ___

- -

1. Load: Binary Tape ______ Binary Deck ______ Patch Cards ______

2. Load: Drum Records
   Tape Lib Records ____________________________

3. I&C Loc _____ = ____________; Loc ____ = ____________

   Loc _____ = ____________; Loc ____ = ____________

4. Set JK __ __ __ __ __ __ : SK __ : Other ________________

5. Set Wds 13,14(Dtg) _____________ Wd15 __ Wd16 __ Wd17 __

   Set A = __________________ Q = ______________

   B1 = ________ B2 = ________ B3 = __________

   BPI = ________ BPO = ________ STO = __________

   Start P = ______ Expected Final ______ Dump Yes ____ No ____

   Dump _____ to ______ Mode ____; ______ to ______ Mode _______

- -

Other Instructions:

(1) Set up for "FWBXB" using tape H-24 (200 Density) as input.
(2) Read in Bi-Octal correction cards.
(3) Run wind 31A on output fields from FWBXB.
(4) Save output on enclosed ST-500 tape.

APPENDIX II

3200 OCTAL PATCH FOR WIND EXTRACTION

02435	64446561
02436	45202020
02437	00000170
02440	00000036
02441	00567000
02442	00160400
02443	63121220
02444	11005305
02445	64634371
02446	44612320
02447	00000170
02450	00000036
02451	00567000
02452	00160400
02453	63121220
02454	11005305
01007	00010201

APPENDIX III

1604 FLEX PATCH FOR WIND WAVES

00705	50 0 12532
	50 0 22351
00706	75 4 05150
	00 0 01400
00707	50 0 22351
	50 0 32170
00710	75 4 05150
	00 0 01400
00711	50 0 32170
	50 0 42007
00712	75 4 05150
	00 0 00100
00713	50 0 61445
	50 0 71264
00714	75 4 05150
	00 0 00200
00715	76 0 00000
	00 0 00000
00632	75 0 00746
	00 0 00000
00751	75 0 01053
	50 0 00000
01056	12 1 51626
	20 1 12532
01057	54 1 07634
	75 0 01056
01060	10 0 00004
	50 1 00000
01061	20 1 32170
	50 0 00000
01062	54 1 07600
	75 0 01061
01063	75 0 01157
	50 0 00000
01173	16 0 01227
	44 1 12532
01175	14 0 01276
	20 1 12532
01177	75 0 01315
	50 0 00000
01211	50 0 12532
	50 0 22366
01530	75 0 01720
	50 0 00000
01724	75 0 02564
	50 0 00000
02007	75 0 02564
	50 0 00000
02602	75 0 03501
	50 0 00000
02566	10 0 00000
	20 1 12532
02600	14 0 01763
	20 1 12532
03553	75 0 01211
	50 0 00000
01026	50 0 10041
	50 0 12002
01027	75 4 05150
	00 0 01400
01030	50 1 00000
	50 2 00000
01031	50 3 00000
	50 4 00000
01032	12 1 10041
	50 0 00000
01033	04 0 00000
	03 0 00014
01034	02 0 00006
	21 2 12532
01035	51 2 00001
	50 0 00000
01036	54 3 00003
	75 0 01033
01037	54 1 01737
	75 0 01032
01040	75 0 01041
	50 0 00000
01041	10 0 22351
	61 0 01034
01042	10 0 01044
	60 0 01040
01043	75 0 01026
	50 0 00000
01044	10 0 12532
	61 0 01034
01045	10 0 01041
	60 0 01040
01046	75 0 00716
	50 0 00000
00716	12 0 00745
	20 0 00737
00717	12 0 00745
	20 0 00733
00720	10 0 32170
	60 0 00735

00721	50 0 10041
	50 0 12514
00722	75 4 05150
	00 0 00100
00723	75 4 00733
	50 0 00000
00724	10 0 61445
	60 0 00735
00725	50 0 10041
	50 0 12514
00726	75 4 05150
	00 0 00200
00727	75 4 00733
	50 0 00000
00730	10 0 32170
	60 0 00735
00731	75 0 00627
	50 0 00000
00745	75 0 00733
	50 0 00000
01214	50 1 00000
	50 2 00000
01215	50 3 00000
	50 4 00000
01216	50 5 00000
	50 6 00000
01217	76 0 01026
	50 0 00000
03560	51 2 00001
	75 0 03554
00761	50 0 00000
	20 0 01270

APPENDIX IV

1604 Run Sheet

Run #7 Date 9-16-66 Est. Time 10 Stop if exceeds ______

Programmer Truax Actual Time ______________

Rush ______ Routine X Rockpile ______ Assembly: AR __ Scrap ______

Ch 3/4 Bioct. __ Bin.Cards ___

Ring

(1) 1000 mb BPI 200 in. ______ out X

(2) SST BPI 200 in. ______ out X

Ch 5/6

Ring

( ) __________ BPI ______ in. ______ out _____ (3) Pool BPI 556 in. X out ___

( ) __________ BPI ______ in. ______ out _____ (4) U,V BPI 200 in. _ out X

- -

1. Load Drum library records "WAVES" (Operational program)
2. Load bioctal tape(s) ______________ Flex tape(s) one
3. I&C Location ______ A(L) __________ A(R) ______________

   ______ A(L) __________ A(R) ______________
4. Set Wd. 10 = ______________ Wd. 16 Pos ______ Neg ______
5. Set Breakpoint ______________ JK 1 2 3 SK ___ ___ 3
6. Set A ____________________ Set Q ____________________
7. Start P = 1026 Expected Final 616 Dump Yes X No ___
8. Dump 600 to 10000 Instr/Data

- -

Other Instructions:

1. Start at 1026 program will stop at 616, hit go
2. Save pool tape if program runs

APPENDIX V

COMPARISON OF RMSE & PILLOW

Date	Derived Waves		Climatological Waves	
	RMSE (FT)	PILLOW (FT)	RMSE (FT)	PILLOW (FT)
28 July	2	0	6	3
29 July	3	1	6	3
30 July	3	1	6	3
31 July	3	1	6	3
1 August	3	1	6	3
2 August	3	1	6	3
3 August	3	1	6	3
4 August	3	1	6	3
5 August	3	1	6	3
6 August	3	1	6	3

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